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**GRO Phase 3 Final Technical Report
for Grant NAG 5 2416
"Time Resolved Spectroscopy of Gamma-Ray Bursts"**

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I. Introduction

The GRO Phase 3 investigation period was from October 1993 through September, 1994, during which Dr. Robert D. Preece received partial support from NASA Fellowship NAG 5-2416, administered by Goddard Space Flight Center. His research activities were directed toward the goals of the BATSE spectroscopy team Key Project proposal entitled, "Time-Resolved Spectroscopy of Gamma Ray Bursts", on which he is a co-investigator. One of the goals was to, "... continue the processing and analysis of... [BATSE] data, including improvements and enhancements...". As for improvements in processing software, much has already been accomplished with the delivery to the Compton Observatory Science Support Center (COSSC) of new data extraction and analysis tools. Some of these tools have been passed on to the general scientific community, along with the second BATSE burst catalog data set, on a CD-ROM. In addition, good progress has been made toward several of the proposal's main scientific objectives, one of which is to produce a comprehensive spectroscopy catalog, and another is a systematic search for spectral features in the BATSE spectroscopy data.

II. Data Processing and Spectral Analysis Software

Several processing steps must be performed upon BATSE telemetry data before it can be used for scientific purposes. Many of these steps have had improvements made, both directly by, as well as under the supervision of, Dr. Preece during the Phase 3 investigation period, and will be discussed below. The general data stream begins at the satellite, and is routed via a TDRSS satellite through GSFC and split into the individual instrument's data. The BATSE data is received at MSFC and converted into a Daily DataSet (DDS), where each data type is separated out from the telemetry stream resulting in a set of individual data files. Triggered data is further processed into an archival format, called the Individual Burst DataBase (IBDB). All of the information necessary to do scientific analysis is present within the IBDB for each trigger, however, each data type retains its original distinct format, which, in addition, is not transportable to different computing platforms. From the files contained in an IBDB, a common-format, transportable data file (based upon the Flexible Image Transport System - FITS) is created by the BATSE FITS program (BFITS). The BATSE detector response matrix (DRM) corresponding to a given trigger, is created in a transportable FITS format by DRM_GEN. For spectral analysis, a program called WINGSPAN was developed, which

reads both BFITS data files and DRM_GEN files and allows the user to select spectra, perform non-linear model fitting and display the results.

At the level of IBDB processing, there were several changes made. There is a need for software to correct data overflows, which arise on the spacecraft due to memory limitations in certain background rate data types. Dr. Preece supervised the development of the background overflow correction software (COR_HER) in its later stages. During Phase 3, this also included software changes arising from revisions in the instrument's flight software. An example of this is a better determination of the actual time when burst data accumulation begins. Also, changes were implemented for certain data types to recover background rate information which is collected immediately prior to the trigger, but had never been used.

BFITS was developed as a method of combining burst and background data (possibly from several different detectors) into a common, easily-readable format, which is also transportable to computing platforms other than DEC VAX's, where the IBDBs reside. Testing, maintenance and support of this software is primarily Dr. Preece's responsibility. Part of this process included designing a suitable common FITS format for the data, regardless of its original data type. This format was chosen for the BATSE 2nd Burst Catalog CD-ROM, which was produced by the COSSC at Goddard Space Flight Center. Dr. Preece made one visit to GSFC, in Oct. 1994, to help in the production process by verifying the integrity of the data.

Methods for calculating the BATSE DRMs were developed by Dr. G. Pendleton of the University of Alabama in Huntsville (UAH). For burst analysis, these routines needed to be automated, and the output standardized, which led to the development of the DRM_GEN program, which was supervised by Dr. Preece. DRM_GEN reads the information it requires directly from a BFITS file, or it can be run using an ASCII NAMELIST file for input. In either case, input parameters, such as the source location, can be overridden flexibly via another NAMELIST file. The output file is again in the FITS format, allowing it to be transportable. In addition, redundant zeros in the upper diagonal of the matrix are suppressed, resulting in significant savings in size (sometimes by a factor of 8 over the size of the matrix in ASCII format). For each data BFITS file on the BATSE CD-ROM, a corresponding DRM FITS file was also included, produced by DRM_GEN.

Finally, to do spectroscopic analyses of burst data, WINGSPAN, a complete data display and analysis environment, was created. WINGSPAN is a hybrid of two separate pieces of software: FITS data reading and display routines (written in the IDL graphics programming language by M. N. Brock at MSFC), and nonlinear spectral model fitting

code (written in FORTRAN by Dr. M. S. Briggs of UAH). Dr. Preece created the new software and has closely overseen its further development. WINGSPAN requires both BFITS files and DRM_GEN files as input for spectral analysis. Among its more powerful features, it can display relationships between fitted parameters in a time series of spectra. It is also able to perform joint fits between several detectors for the same burst, including both the BATSE Large Area (LAD) and Spectroscopy Detectors (SD). We are working on porting the software to different platforms, to ensure its wide-spread availability. A multi-platform version of WINGSPAN, which can read and display burst data, was also selected for inclusion on the BATSE CD-ROM.

III. Spectroscopy Science Goals

One of the important investigations that BATSE is uniquely qualified to perform is high time-resolution GRB spectroscopy. This investigation divides into several areas of research, including: spectral evolution of individual bursts, spectral components of burst continua and burst spectral features, such as line emission or absorption. Progress in each of these three areas will be discussed.

It is hoped that a close examination of changes in a burst's spectrum over time can lead to a better understanding of the underlying emission mechanism. To complement a spectral evolution study undertaken with data from the BATSE SDs, a similar project was begun using LAD burst data by Dr. Preece. The LADs have two advantages over the SDs for spectral evolution studies: the first is that the larger collecting area means better count statistics, allowing spectral fits on a finer time scale, for a given signal to noise ratio. Thus all bursts can be examined at a higher time resolution, and dimmer bursts can be included in the study. The higher count rates of the LADs also better constrains the spectral shape in the higher energy bins, where the count rates are usually lowest. The high energy spectra of bursts are usually described as power law; the present study will investigate this hypothesis, and determine how the power law segment behaves on time scales shorter than individual peaks in the time history.

Some claims have been made for evidence of several spectral components, each changing on a separate time scale, which make up the burst continuum. In particular, some Ginga burst seem to show a separate X-ray component, which may precede or linger after a burst. The BATSE SDs have the capability of obtaining count rates from a band from 5 to 10 keV, however the actual energies covered by this data was previously not well determined. As implemented, the energy covered ranges from that of the SD Lower Level Discriminator (LLD) down to half the LLD. An in-orbit cycle through

several LLD settings (which are commandable from the ground) for each of the 8 SDs gave values which could be compared with ground measurements made before launch. This allowed Dr. Preece to make a mapping from the LLD setting to channel number, from which he determined the energy (using the current channel-to-energy conversion routine by Dr. D. L. Band at UCSD). Data in this energy band can now be included in a joint fit with SD burst data. When this is done with solar flare data, the discriminator data falls on top of the extrapolation downward in energy of a fit from a low-energy thermal component to the spectrum. For bursts, the preliminary result of a catalog of BATSE bursts made by Dr. Preece is that some bursts require no extra low-energy spectral component, some have a deficit of low energy counts relative to a single continuum component, and some seem to have an excess of counts.

Evidence for spectral features, or failing that, proof of their absence, is an especially important effort in burst spectroscopy. In particular, a detection of cyclotron absorption line features could bear directly on the controversy of the burst distance scale. Most of the effort to look for line features in the BATSE data has been focused upon the higher energy-resolution SDs. Part of the WINGSPAN software development was directed towards supporting an automated search of the data for narrow line-like features. Once a satisfactory background model and source spectra have been selected within WINGSPAN, the data is packaged for further processing by specialized software, in a format which can be exchanged among each of the co-investigating institutions. In a different vein, Dr. Preece has shown that the BATSE LADs, due to their large collecting area, can overcome the limitations of poorer energy resolution than the SDs in the detection of line features in spectra. The LAD data, can serve as an important consistency check for any line features detected with the SDs. Once overflows in the background data were straightened out, however, it became clear that a correction of the LAD channel-to-energy conversion technique had to be performed, as it had been done for the SDs earlier. Otherwise, most high signal-to-noise LAD spectra would contain systematic line-like departures from a fitted continuum, masking the detection of any features intrinsic to an individual burst spectrum. A preliminary correction, based upon 16 channel occultation data of the Crab source by Dr. G. Pendleton of UAH, reduces the systematic wiggles somewhat and has been used for the continuum investigations, described above. A more comprehensive adjustment is planned by Dr. Preece, which uses most of the 128 channels of the LAD Burst data.

IV. Publications in Refereed Journals

1. 1994 "BATSE Observations of the Very Intense Gamma-Ray Burst GRB930131", C. Kouveliotou, R. Preece, N. Bhat, G. Fishman, C. Meegan, J. Horack, M. Briggs, W. Paciesas, G. Pendleton, D. Band, J. Matteson, D. Palmer, B. Teegarden & J. Norris, *ApJ*, 422, L59.
2. 1994 "The Rarity of Soft g-ray Repeaters Deduced from Reactivation of SGR1806-20", C. Kouveliotou, G. Fishman, C. Meegan, W. Paciesas, J. van Paradijs, J. Norris, R. Preece, M. Briggs, J. Horack, G. Pendleton & D. Green, *Nature*, 368, 125.
3. 1994 "BATSE Gamma-Ray Burst Line Search. I. Search for Narrow Lines in Spectroscopy Detector Data", D. Palmer, B. Teegarden, B. Schaefer, T. Cline, D. Band, L. Ford, J. Matteson, W. Paciesas, G. Pendleton, M. Briggs, R. Preece, G. Fishman, C. Meegan, R. Wilson, J. Lestrade, *ApJ*, 433, L77.
4. 1994 "BATSE Gamma-Ray Burst Line Search. II. Bayesian Consistency Methodology", D. Band, L. Ford, J. Matteson, M. Briggs, W. Paciesas, G. Pendleton, R. Preece, D. Palmer, B. Teegarden, B. Schaefer, *ApJ*, 434, 560.
5. 1995 "BATSE Observations of Gamma-Ray Burst Spectra. II. Peak Energy Evolution in Bright, Long Bursts", L. Ford, D. Band, J. Matteson, M. Briggs, G. Pendleton, R. Preece, W. Paciesas, D. Palmer, B. Teegarden, B. Schaefer, T. Cline, G. Fishman, C. Kouveliotou, C. Meegan, *ApJ*, in press.

V. Professional Travel

1. BATSE Spectroscopy Team Meeting at UCSD in La Jolla, CA on Feb. 17 & 18, 1994.
2. Travel to GSFC for the purpose of working on data for the BATSE CD-ROM, Greenbelt, MD, Oct. 10-12, 1994.
3. 1994 Meeting of the AAS High Energy Astrophysics Division, Napa Valley, CA, Nov. 2-5, 1994.